

Structure

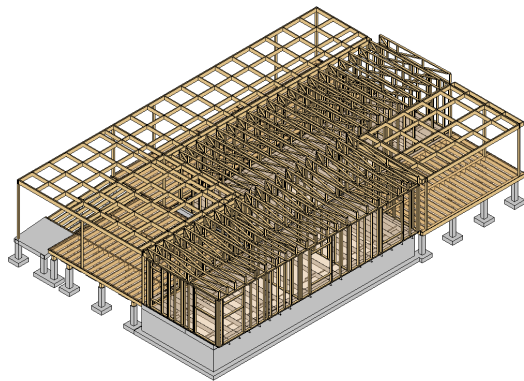


Figure 1. Isometric view of structural components

The structural system was thoughtfully designed to address architectural and MEP systems' requirements, which resulted in an integrated, functional, and efficient layout compatible with all disciplines. The benefits of the many systems were considered, and we chose to opt for the vierendeel truss. Its minimally sloped shape is ideal for our architectural requirements of roof thermal insulation, and MEP systems can be effectively integrated while maintaining structural efficiency. The thermal efficiency was increased due to reduced envelope openings.

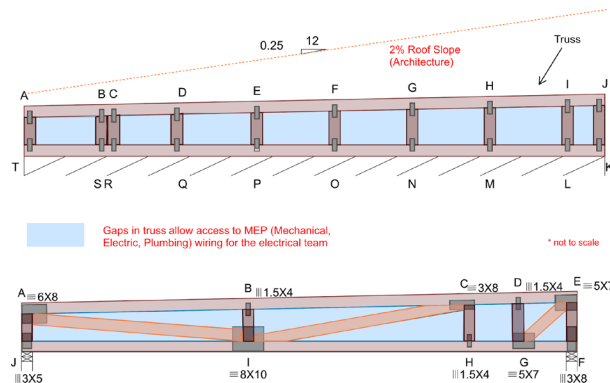


Figure 2. Interdisciplinary solution to roof trusses

The need for adaptable design that keeps structure integral with installation of new modules for future expansion was crucial for structural framing selection. The reusability of prefabricated building components made its installation convenient along with better construction tolerance and quality control. This approach is more efficient compared to on-site assembly which resulted in reduced costs for the occupants. The prefabricated components are more consistent as they are manufactured under regulated temperatures. It was ideal to use an independent structure for decking and canopy to align with the architectural concept of future expansion and contraction of modules. This led to a better air tight seal in the envelope and the discontinuous structure mitigated thermal bridging issue.

The structural analysis was performed in SAP2000 for different loading combinations. It provided visualization of members' health under the specified loadings along with information about load, shear, moment, and deflection diagrams. The design was verified manually and stamped by licensed structural engineer at Thornton Tomasetti. Simpson Strong Tie software was used to analyze the structural member connections and the characteristics of joints in our structure. This provided information for draft calculations as well as insights on design efficiency. The structure's resiliency for typical building loads was ensured using the ASCE 7-16 standards, with weather conditions also factored in.

Water

The plumbing design prioritizes the conservation and efficiency of water consumption through an optimal layout integrated into the design of other sub-disciplines. The plumbing and fixtures were consolidated in one corner of the home, thus reducing piping materials and optimizing future accessibility and ease of maintenance, while complying with the Illinois Plumbing

Code. The tankless water heater is located in the mechanical room, which is conveniently located between the kitchen, bathroom, and laundry area thus increasing the efficiency of hot water delivery to all fixtures. In collaboration with the structure and architecture sub-teams, we utilized a false wall in the bathroom to conceal plumbing pipes. ADAPTHAUS' low-flow fixtures and water-efficient appliances result in approximately 29% less total indoor water consumption compared to the EPA's 1992/2005 baseline. A basic fire protection system (one detector per module) was selected for simplicity of design and maintenance.

Smart Integration & Homeowner Interaction

To encourage sustainable water consumption by the homeowner, our indoor water system is monitored with [StreamLabs Home Water Control](#), a smart water shut-off valve that is installed directly into the main water line. It utilizes ultrasonic sound waves to measure water flow and detect potential

problems such as leaky pipes, appliance failures, and freezing conditions. Real-time data is sent to the StreamLabs mobile application through Wi-Fi, enabling the homeowner to take action remotely. With this smart water technology, homeowners will be more involved and informed about their water usage and avoid excessive water consumption, water damage, insurance claims, and repair costs.

Greywater Reuse for Landscape Irrigation

As part of our water conservation initiative, we aim to minimize potable water use for landscape irrigation. Since Midwest homeowners prefer luscious lawns and gardens, greywater reclamation for irrigation is an invaluable opportunity to reduce potable water consumption and strain on municipal water systems. However, Illinois currently does not have greywater-specific codes or provisions. Given the many potential benefits of greywater reclamation and reuse, any advances in the acceptability of greywater in Illinois could

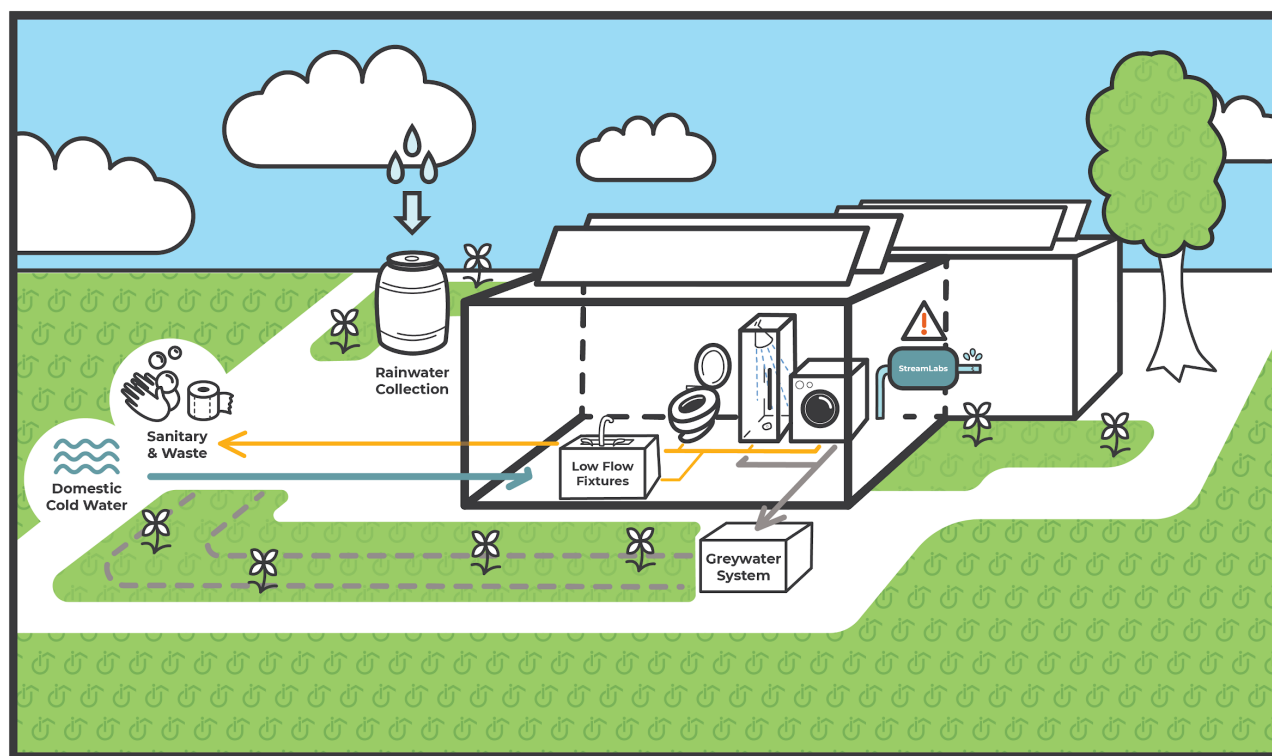


Figure 3. Plumbing System and Proposed Greywater System

have far-reaching impacts - reducing strain on municipal wastewater systems, reducing combined sewage overflows, decreasing energy consumption used for water treatment, and conserving water resources. We opted to design a subsurface greywater irrigation system due to its simplicity, safety, and cost-effectiveness, and are currently in the process of applying for a variance from the state. Implementation and use of this system will potentially lead to 5,700 gallons of water available for irrigation.

The system reuses shower and laundry water from ADAPTHAUS for subsoil irrigation of plants. This maximizes irrigation efficiency, as water is delivered directly to the root zone of plants, greatly reducing water loss through surface runoff and evaporation. We collaborated closely with the Landscape sub-team to optimize the piping layout and water delivery to the vegetation area. All plants selected for the greywater system are inedible, to comply with greywater regulations and best practices. The system itself is entirely gravity-fed and automated.

The system was designed for a daily flow of 80 gpd. Greywater will be dual plumbed

to a three-way diverter valve, which sends greywater either towards the sewer or the subsurface irrigation system. When active, greywater flows through a buried 300-gallon settling tank. The water enters and exits the tank via an ABS Schedule 40 pipe, and is distributed into customized dispersal (aquifer) piping designed to distribute water below the plant root level, creating a virtual water table that encourages natural root growth into the saturated zone. In consideration of the local climate, the system will only be active from June to August. For the rest of the year, the system will automatically be deactivated and its flow will be sent to the sewer. This will avoid early freezing in the fall and late freezing and seasonally higher groundwater in the spring. Diversion occurs automatically using a smart irrigation controller wired to the diverter valve and programmed to send flow to the sewer during the period described, following heavy rains during the active season, or manually at the discretion of the homeowner. The irrigation controller also allows the homeowner to tailor the greywater system to their irrigation needs, through functions such as automatic weather

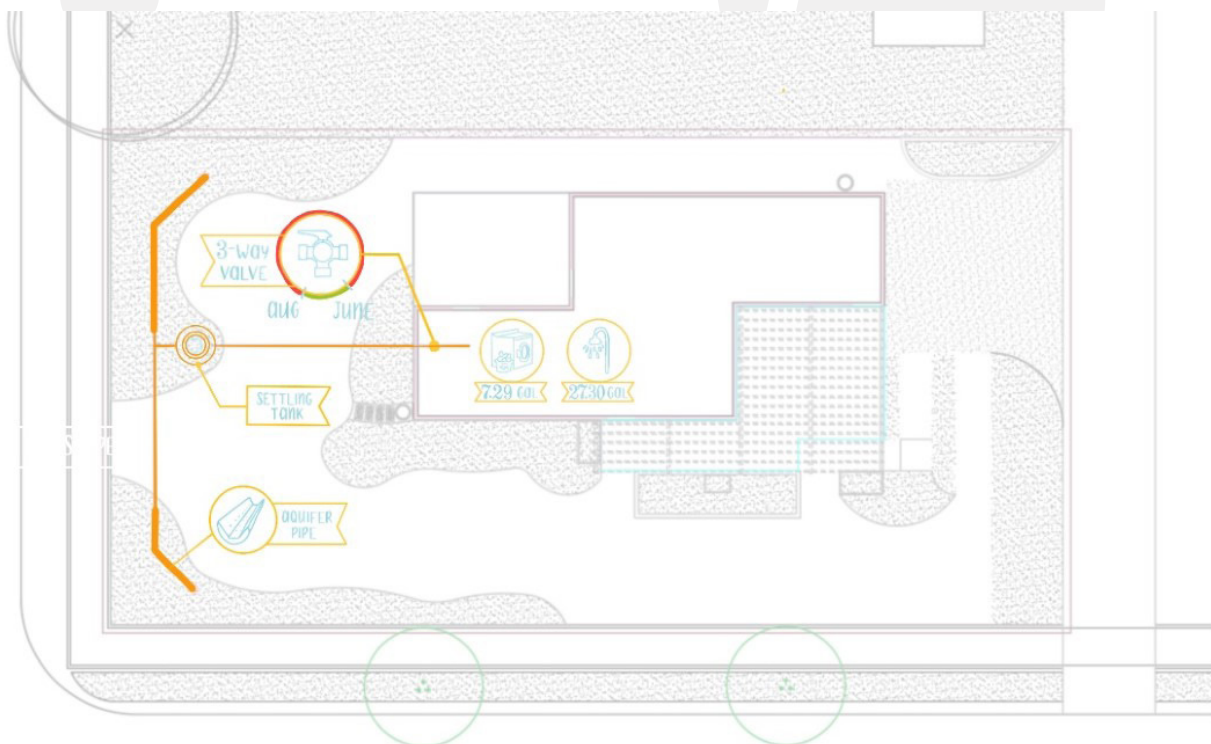


Figure4. Greywater System

adjustments, multi-control options, and real-time remote operation.

Rainwater Harvesting

Rainwater will be harvested in 100% recycled plastic rain barrels, to support the greywater reuse system in reducing potable water consumption. The homeowner is free to choose where to utilize the rainwater, such as vegetable gardens, planter beds, and other beds not close to the irrigation pipes. With average annual precipitation slightly higher than the national average, these rain barrels can result in significant water savings and offsetting of potable water consumption for irrigation.

Efficient Hot Water Delivery

For hot water delivery, we selected the energy-efficient EcoSmart 27 Electric Tankless Water Heater. It is equipped with flow rate and temperature sensors, and a compact and less expensive option than the conventional hot water tank. The tank was originally sized for a slightly larger home, which allows for future adaptability and adequate hot water delivery if the homeowner decides to add on an additional module. While all of the plumbing fixtures and water heater are located in one compact area, the water heater is optimally located in the middle of all the hot water fixtures - the kitchen sink, dishwasher, laundry machine, shower, and bathroom sink. Cross-linked polyethylene (PEX) tubing from Sharkbite was selected to supply hot water due to its flexible and resilient properties. PEX tubing is easy to maintain, chlorine resistant, and does not corrode. Advantages of PEX tubing over traditional copper piping include higher resistance to breakage caused by freezing, heat loss and scale buildup, along with reduced need for elbows and transition fittings due to its flexibility. Our PEX tubing is securely located in the crawl space to avoid environmental damage to the pipe material over time.

Heating, Ventilation, and Air Conditioning

HVAC system design is based around the concept of adaptability in the home. The two main parts of our HVAC system are a mini-split 12k BTU Mitsubishi AC system and a BuildEquinox CERV2. We have chosen the Mitsubishi 12k BTU AC over other capacity ACs because a mini-split system integrated well with this concept of adaptability. It is much easier to expand the mini-split system into future additions to the home versus other systems.

The Mitsubishi 12k BTU P-Series AC was the choice for our HVAC system for a number of reasons. First, the indoor unit is designed to conceal itself directly into the ceiling, saving on the limited amount of space available in the home. Secondly, the AC unit is a 12k BTU unit, meaning we will be able to save energy when operating the HVAC system constantly. Lastly, the Mitsubishi P-Series uses an inverter-driven compressor which allows for high speed heating at start up saving about half the time compared to other units as well as making the Mitsubishi P-Series dramatically more energy efficient. Figure 3 shows both the outdoor and indoor units of the Mitsubishi P-Series.

The main purpose of the BuildEquinox CERV2 is to act as an energy recovery ventilator with the function of ensuring air comfort as well as monitoring air quality. The BuildEquinox CERV2 is a compact unit that expands on the functionality of a typical ERV. The CERV2 will have additional monitors and controls to help improve air quality. These monitors will track carbon dioxide and Volatile Organic Compounds (VOC) and choose to ventilate the house if the levels become dangerous. This feature allows us to maintain high air quality that improves the health, cognition, and sleep quality of residents. Extra features can be added onto the CERV2 which will further improve air quality. This includes the CERV-UV, which

integrates UV germicidal irradiation directly into the system. The CERV-Intelligent Relay is an addition that better integrates the control over the CERV2 and Mitsubishi mini-split. The CERV-IR connects with Mitsubishi's thermostat and simplifies control of comfort. The CERV2 is also paired with an app named "CERV-ICE" which allows the user to monitor and change settings directly from their mobile device. The app also provides the user with historical indoor air quality data and comes standard with each CERV2. Wireless sensors can also be added to the system, which for example can alert the CERV2 to go into ventilation mode when someone enters the bathroom, or to turn off heating/cooling when a window or door is open.

Overall the goal of our system is to keep an in-door temperature of 72 degrees, relative humidity between 35% to 50%, and carbon dioxide level below 1000 PPM year-round. The system will be integrated into the software developed by ISD as well. The HVAC system was designed in collaboration with other disciplines within the Build Team. We communicated with the Architecture team when selecting the materials for our system to make sure everything was integrated seamlessly. We also ran energy simulations using ZEROs and based on the results we found that our design used 15% less energy than design without the CERV2. Due to the single-story design of the project, air stratification was not an issue when designing and implementing our system

Figure 3 shows a top-down perspective of the HVAC system. In the bottom left corner of the drawing, is the mechanical room which contains our equipment. Stemming from the mechanical room are the blue ducts which is our supply air and the pink ducts which is the return air for our CERV2 unit. The small green squares that you see are the exhaust fans for the bathroom.

Figure 4 shows a closer look at the mechanical room. The larger black unit at the bottom of the figure is the BuildEquinox CERV2 system. The pink ducts are feeding return air back into the unit and the small blue tube you

see is providing supply air. The two green pipes connected to the CERV are connected to the outer wall, working as a fresh air intake and exhaust air outlet. Right above the black box is the indoor AC unit. This unit is also supplying air to the home.

Design Considerations

According to the City of Champaign, Illinois local regulatory agency, there is no building code regarding the design of HVAC systems for single-family housing and the design is compliant with the Solar Decathlon Building Code. As a result, considerations of feasibility, efficiency, and sustainability are the focuses of the HVAC design.

For feasibility, structural and architectural constraints have been taken into considerations when determining the design of ducts and locations of equipment. We have also designed our system to be easily accessible from inside the mechanical room which will provide the resident a convenient space to access and maintain the equipment. One of the reasons for choosing a mini-split system is that it allows easy expansion for more housing modules. We considered space when deciding where to place our air intake and air outlets. Each room has its own air supply and the air return is positioned in the bottom left-hand corner of the house (See Figure 3). This allows for quality air mixing throughout the entire building by taking advantage of the air pressure difference.

For sustainability, price-performance ratio, the ability of energy recovery, and suppliers' attitude towards sustainability are considered. For efficiency, the system is designed to minimize the duct length of the system. Furthermore, ZEROs, developed by BuildEquinox, is used for examining the efficiency of our design. Figure 5 and Figure 6 in the Appendix show the monthly total electricity load, electricity consumption breakdown within a typical year. The Figure 7 shows the relationship between the daily electricity consumption and the local temperature.

In addition, the estimated yearly energy load for heating is 433.8 kWh (1.48 MMBtu), and

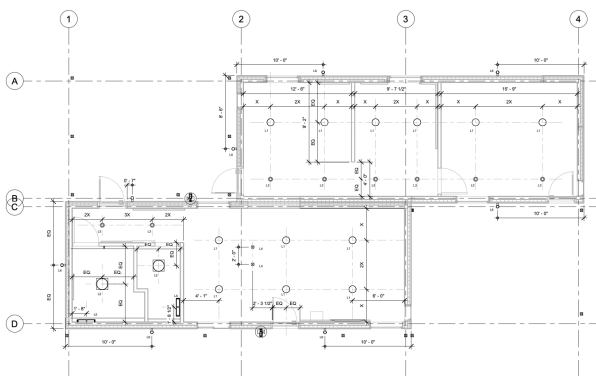
that for CERV is 987.1kWh (3.37 MMBtu). Since CERV has a function of conditioning air, and cooling needs in the locality of the project are not large, no extra cooling load is needed.

Lighting

The lighting design philosophy is to optimize the energy usage of lights along with the consideration of natural light and smart controlled appliances. The interior of ADAPTHAUS is illuminated with energy-efficient LED lighting. We also plan to use sunlight sensors and automatic blinds that sense natural light and dim the electrical lights accordingly. This takes advantage of natural light and is an energy-efficient way to light a home. Natural light is not only a mood booster, but the right balance of windows and insulation will provide enough heat to maintain thermal efficiency.

Our outdoor lighting will be solar-powered, lighting a clear path from the driveway to the door and providing a welcoming ambiance in the garden. By using energy-efficient lighting we can reduce the overall need for energy throughout the home.

Figure 5. Lighting Layout



Home Automation

and Appliances

Many components of the home, such as an energy monitor, a smart TV, and smart plugs, will be integrated with Alexa to elevate the house to a smart home. We have also selected Energy Star certified and ADA-compliant appliances to improve the energy efficiency and accessibility of the house.

We are using the Sense Solar Energy Monitor to track the energy generation from the solar panels as well as the energy consumption of individual components within the home. By monitoring the energy production and consumption patterns over time, the residents can modify their habits to shift large loads to more optimal times. For example, they can learn to charge their electric vehicle at noon when the energy production is the highest. The integration of all of the appliances could help the users enroll in future demand response programs. By understanding exactly how much energy each component of the home is consuming, the user would be able to take action with specific targets for improvement.

We also plan to outfit the home with a state of the art security system, keeping the occupants confident that their home is well protected. The compatibility with Alexa allows the resident to conveniently manage the system.

Photovoltaic System

The Photovoltaic system of ADAPTHAUS was designed with the goal of making it a positive energy home, while highlighting our central theme of adaptability. It consists of two highly efficient monocrystalline photovoltaic arrays, a combination of a hybrid and grid-tied inverter along with a sustainable battery storage solution, all sized to maximize on-site energy production while meeting the energy demands of our

increases until a 150 tilt, after which the inter-row shading takes precedence and reduces the energy output (See Figure 3). Combining this with the ease of installation aspect, we chose Unirac's RM10 ballasted flat-roof racking system. This provides a 100 tilt for our modules and 12 inches spacing between rows, providing maximal production with no inter-row shading, while ensuring convenient installation. The choice of ballasts over screw mounts for our racking system ensures that the building envelope is unaffected and minimizes energy loss from the inside.

Diagram illustrating a solar power system configuration with battery storage:

- Solar Panels:** Two strings of Mission Solar PERC 60 Solar Panels (String of 12 panels) are shown.
- Inverters:** The solar panels are connected to an Outback Skybox Inverter and a SolarEdge Inverter.
- Battery Storage:** A BigBattery Energy Storage unit is connected to the Outback Skybox Inverter.
- Electrical Panels:** The Outback Skybox Inverter is connected to a Critical Loads Panel and an AC Disconnect. The SolarEdge Inverter is connected to an AC Disconnect.
- Main Breaker Panel:** Both AC Disconnects are connected to the Main Breaker Panel.
- Utility Meter:** The Main Breaker Panel is connected to the Utility Meter.
- Grid Connection:** The Utility Meter is connected to the grid (To grid).
- Home Connection:** The Main Breaker Panel is connected to the home (To Home).

Figure 6. PV System Configuration

Our PV system comprises 24 Mission Solar MSE320SR8T modules, each with a nominal power output of 320W for an overall system size of 7.6 kW. The Mission solar panels are one of the best residential solar panels with a conversion efficiency of 18.94%. The system is divided into two arrays with connections to a grid-tied SolarEdge inverter and an Outback Skybox hybrid inverter. The first array of 12 modules is connected to the Outback Skybox. The Skybox is an intelligent hybrid inverter with MPPT trackers that can operate both on and off-grid using one integrated inverter module. The next array of 12 modules is connected to the grid-tied SolarEdge inverter. A slight tilt provided to roofs of both home modules facilitates roof water drainage and can be detrimental to

these PV modules. This is mitigated using power optimizers on the modules, which minimizes shading and mismatch losses. During off-grid operation, the skybox inverter automatically switches to off-grid mode and utilizes the power from the 12 PV modules and the 10.6 kWh to power the critical loads of our home.

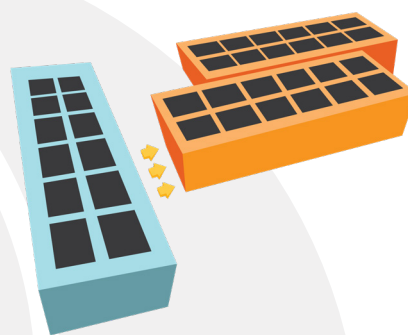
Battery System

ADAPTHAUS uses two 5.3 kWh low-voltage batteries connected in parallel from BigBattery to support its PV system and provide reliable backup power. Repurposed from used car batteries, this technology curtails battery waste, has the lowest associated carbon footprint, and makes our home more sustainable. BigBattery costs 50% less, has a 100% depth of discharge (DoD) and is more durable than its lithium-ion competitors for the same capacity, making it a highly cost-effective solution. The battery stores power from the PV array which can be utilized later for time-of-use and grid islanding applications. This ensures maximum value utilization from the battery while mitigating utility charges for the homeowners.

Adaptability

Our photovoltaic system is also able to evolve over 20 years which is at least a third of the lifecycle of the house, according to the needs of the occupants without needing to replace the system. Despite our system being cheaper than a similar sized AC or DC coupled system, our system is not at maximum capacity. Thus, should the occupants of ADAPTHAUS choose to add another module to expand the house, we can accommodate up to 8 additional PV modules on the SolarEdge string. The PV System would be able to generate 11,200 kWh/yr which can sustain an additional home module assuming a family size of 4 - 5. As no additional Balance of System (BOS) components are required to increase the system capacity, the occupants can

easily expand their system at minimal costs which complements our mission of being adaptable and modular. Despite being comparable to a DC coupled system with a backup solution in terms of performance while being more cost-effective, our design is a lesser known option. Hopefully, our design can serve the purpose of exposing the people in Champaign who are interested in installing a hybrid PV system to our more cost-effective design.



**Figure 7. PV System-
Future Modularity and
Adaptability**

Energy Analysis

By using BEOpt energy analysis software, ADAPTHAUS' annual energy consumption only reaches 7600 kWh at 1120 sqft which is roughly 61% less than an average Illinois household at 19520 kWh based on 2009 data. The PV system is able to produce 9600 kWh of electricity a year thereby making the building net negative in terms of energy use. Additionally, between March to October, electricity from PV could already provide 100% of ADAPTHAUS' annual consumption. Due to the application of heat pump during the winter months, the PV system will not sufficiently provide daily energy consumption during the winter months. However, the implementation of net metering allows ADAPTHAUS to have reliable electricity at all times.

Architectural

Solar Passive Design

The two modules that conform this house are planned to optimize the intake of natural light, taking advantage of the site orientation and managing glare through passive shading strategies. East facing windows are designed with overhangs made of the same wooden material as cladding to control glare, while south facing windows are offered shade through the exterior canopy of the house, while paralleling optimizing natural light intake. North facing windows do not use passive shading elements, and acquire additional natural light access in Module C. Artificial light in the interior of the house is also thought as a sustainable system, utilizing only efficient LED lights to reduce energy consumption and offer long durability for the users.

Envelope and building science

To follow the premise of sustainability as

a guiding principle in this project, the building envelope of this house was designed as a fundamental energetic performance feature of the overall design. The envelope design is based on the local climate of Champaign, IL, and thus features continuous insulation outside the structure to alleviate thermal bridging. The R values that are achieved with the envelope design are R28 for walls, R33 for floors, and R62 for the roof. Since the wooden frame structure used in this house has a relatively high thermal conductivity, the continuous insulation is utilized around the wood frame to reduce the risk of thermal bridging. Closed-cell spray foam insulation in the cavity between the stud joists reduces the thickness of the continuous insulation and maximizes interior space. The continuous insulation reduces the risk of condensation since the temperature of the interior face of the sheathing is raised above the dew point. The fluid-applied water resistive barrier acts as an additional air barrier and is vapor permeable. In order to achieve 0.03 ACH airtightness, ADAPTHAUS utilizes the low air permeability of the closed-cell spray foam cavity insulation. The roof utilizes Ethylene Propylene Diene Monomer (EPDM) membrane

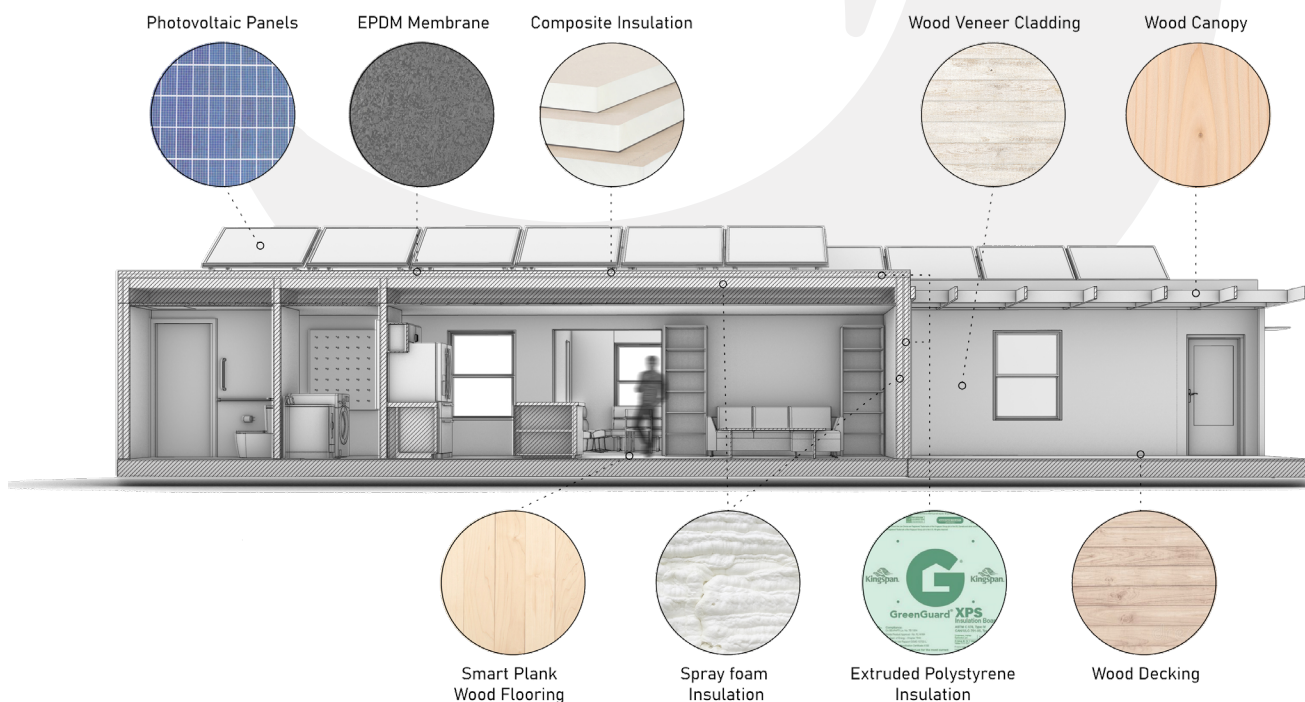


Figure 8. Building envelope diagram

on the outer surface. On the outer layer of this robust thermal envelope lies wooden cladding elements that provide additional insulation capacity to the general structure and are merged with some of the other exterior visual elements of the house, composed of wood, as are the decking and canopy. All the windows of the project are double-pane glass, helping maintain an optimal performance throughout the envelope.

Envelope and HVAC

The envelope of the house optimizes energy efficiency by maintaining a good thermal control of the space throughout the seasons, and is complemented by a robust HVAC system which mainly consists of the CERV2 ventilation system and a Mitsubishi M-Series mini-split system. With our integrated design, the two systems work together efficiently, keeping the indoor environment healthy and comfortable.

HVAC Appendix

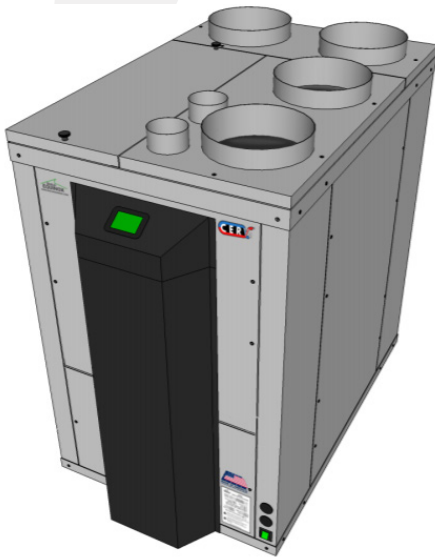
Indoor Unit:
PEAD-A12AA7



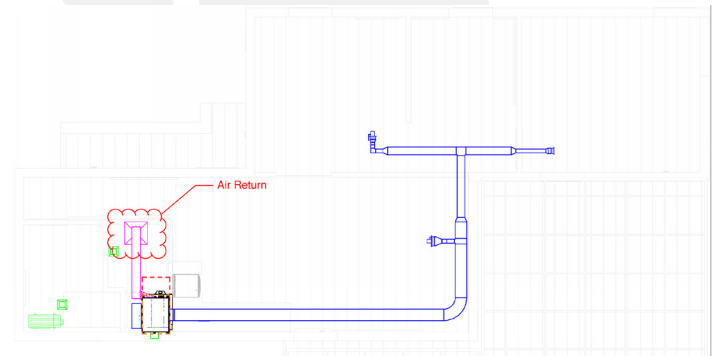
Outdoor Unit:
SUZ-KA12NAHZ



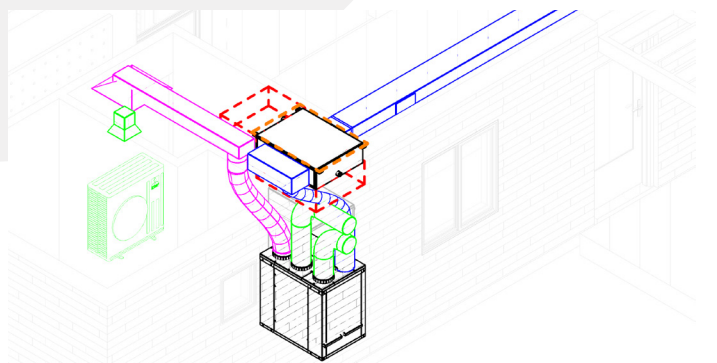
HVAC-Figure 1: Mitsubishi 12k BTU P-Series AC Unit



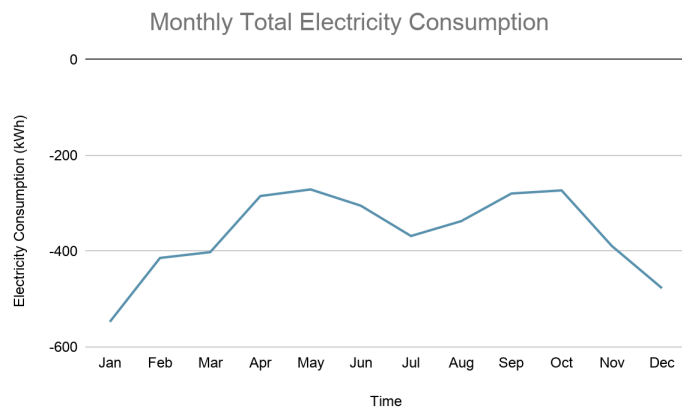
HVAC-Figure 2: BuildEquinox CERV 2



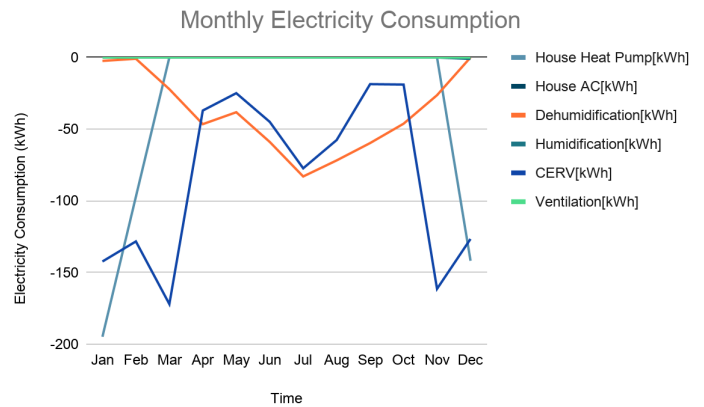
HVAC-Figure 3: Revit Model of HVAC System



HVAC-Figure 4: Revit Model of Mechanical



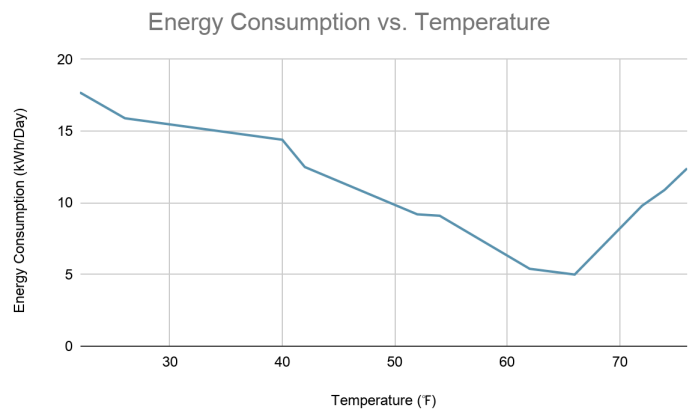
HVAC-Figure 5. Monthly Total Electricity Consumption in a Year
Note 1: Consumption is considered as negative value in this figure



HVAC-Figure 6. Monthly Electricity Consumption in a Year

Note1: Electricity consumption of non-HVAC components is not included.

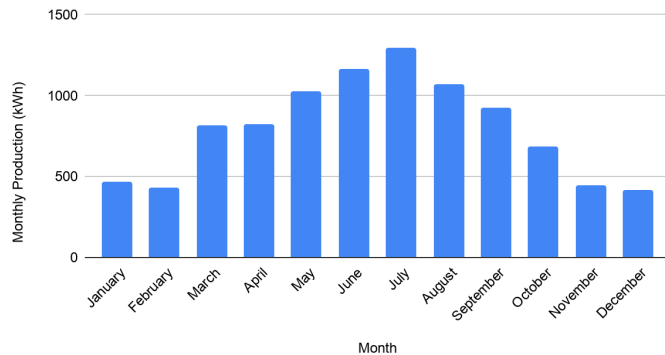
Note2: Consumption is considered as negative value in this figure



HVAC-Figure7.ElectricityConsumption vs. Temperature

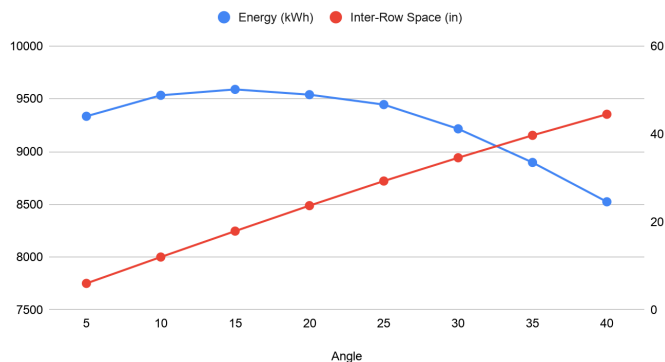
PV- Appendix

Monthly Production (kWh) vs. Month



PV&E - Figure 1 PV System Monthly Energy Production

Energy (kWh) and Inter-Row Space (in)



PV&E - Figure 2 Energy/ Inter-Row Spacing vs Tilt Angle

PVWatts Calculator

RESULTS

1,306 kWh/Year*

System output may range from 1,230 to 1,355 kWh per year near this location.

Month	Solar Radiation (kWh / m ² / day)	AC Energy (kWh)	Value (\$)
January	2.58	67	6
February	3.29	76	7
March	4.28	108	10
April	5.59	133	12
May	5.94	142	13
June	6.65	152	14
July	6.59	153	14
August	6.10	142	13
September	5.33	120	11
October	3.86	94	9
November	2.77	68	6
December	2.03	52	5
Annual	4.58	1,307	\$ 120

Location and Station Identification

Requested Location	1202 North Walnut Street, Champaign, Illinois		
Weather Data Source	Lat, Lon: 40.13, -88.26	1.0 mi	
Latitude	40.13° N		
Longitude	88.26° W		

PV System Specifications (Residential)

DC System Size	1 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	10°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2

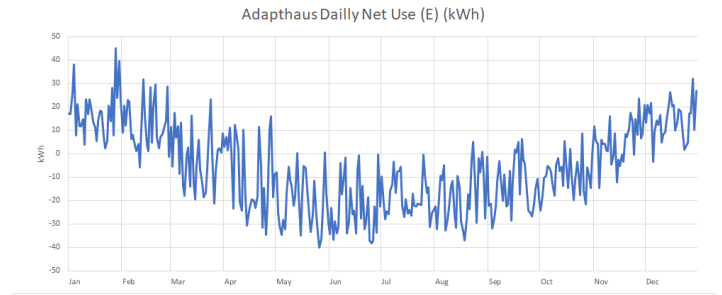
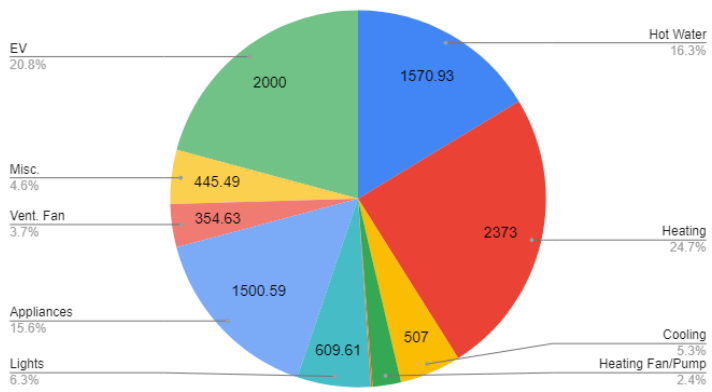
PV&E - Figure 3 Energy Production for a 1kW PV system in Champaign, Illinois

System Sizing

The total electrical load calculation of the building shows that ADAPTHAUS consumes 7338 kWh of electricity annually. The electric vehicle accounts for an additional 2025 kWh of annual energy consumption. This gives us a total of 9363 kWh of electric energy to be balanced by the PV system. Using the tilt angle and azimuth as input parameters in PVWatts, the energy production from a 1kW system in Champaign was calculated to be 1306 kWh/year. In order for ADAPTHAUS to be net-zero, the PV system size can be calculated as:

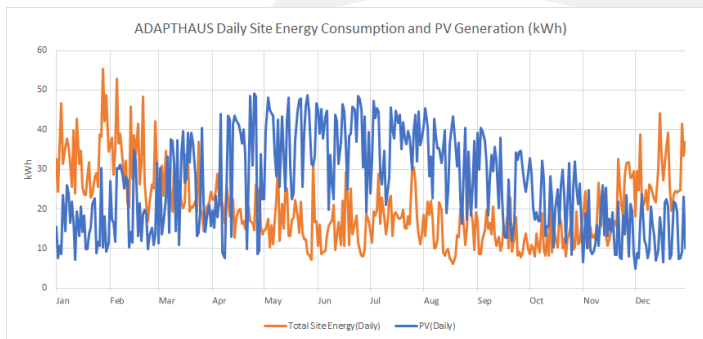
$$\text{PV System Size} = 1 \text{ kW AC} / 1306 \text{ kWh/yr} \times 9338 \text{ kWh/yr} = 7.16 \text{ kW.}$$

Annual Energy Use with EV(kWh)

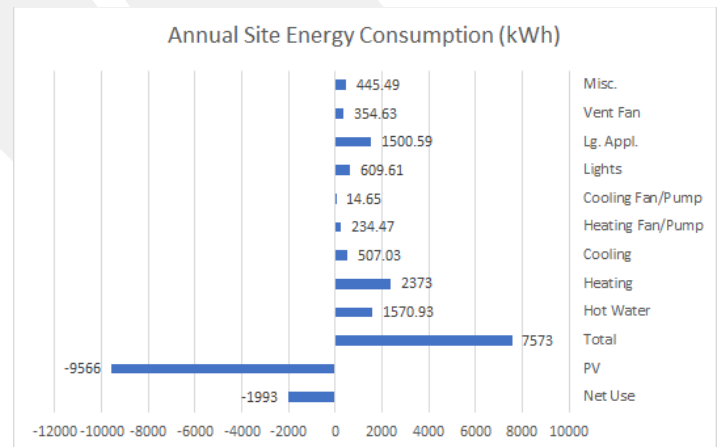


PV&E - Figure 7 Daily Net Use of ADAPTHAUS over the year

PV&E - Figure 4 Annual Energy Usage with EV (kWh)



PV&E - Figure 6 Daily PV Generation(Blue) and Total Site Energy Usage(Red) over the year



PV&E - Figure 5 Annual Site Energy Consumption of each Load Types